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APPLIED METHOD FOR DESIGN OPTIMIZATION OF HYDROSTATIC GUIDEWAY ON REAL MACHINE TOOL

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Abstract: *The main advantages of hydrostatic bearings are: design flexibility, excellent structural damping, and zero friction at low speeds; this is a great opportunity for various types of machine tools. However, the need to determine many parameters at the design stage and a lack of a general approach to their optimization pose a large obstacle to wider application. This paper suggests a general iterative method for design optimization of hydrostatic bearings for linear and low-speed rotary axes. The method uses automated generation of load combinations, multi-objective optimization for determining design parameters and FEM for predicting structural deflection of machine frame parts.*

Keywords: ***Hydrostatic, guideway, bearing, optimization.***

1. Background

General requirements for guideways of motion axes include smooth movement with low resistance at all speeds and loads, high load capacity, high stiffness, long service life, good damping properties, and high precision.

Hydrostatic (HS) guideways represent one of the guidance types ensuring linear and rotating movement of machine tool parts that fulfil the above-mentioned requirements. The use of HS guideways in engineering is of a relatively recent date: with some earlier exceptions, this type was introduced in the 1960s and 1970s (Lewis, 1966). The main component of a HS guideway is a HS pocket containing pressurized fluid. This guideway type is a very good option for high-precision machines, machines requiring very small positioning steps, machines for hard machining (high damping needed), and large machines (design flexibility needed). Conditions for HS operation:

- Very thin fluid layer (gap height) in the bearing (*5* to *200* μm);
- Sufficient parallelism and planarity of bearing surfaces in all operating modes;
- Very low fluid compressibility;
- Relatively constant viscosity of fluid (stable temperature).

In practice, a distinction is made between two types of HS guideways: open guideways (preloaded by gravity of parts or other dominant load) and closed guideways (mutually preloaded pockets placed opposite each other).

HS guideway can generally operate in two operating modes corresponding to the settings of the hydraulic unit and the flow control methods (Weck & Brecher, 2006):

- Constant flow provided by the pump (One pump for each pocket, Flow dividers);
- Constant pressure provided by the pump (Control by means of constant hydraulic resistance such as capillary tube or orifice plate, advanced flow control such as PM flow controller or membrane controller, self-compensating systems used especially for radial HS bearings).

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2. General design method

The primary aim of this paper is to present an iterative approach to optimizing the entire design process for HS machine tool guideways (lacking in the available literature), combining the *finite element method* (FEM) and multiparametric, multi-criterion optimization. The method is robust, taking into account all possible load situations which can arise in operation, and is not dependent on the selection of a specific optimization criterion. A diagram showing whole process is depicted below.

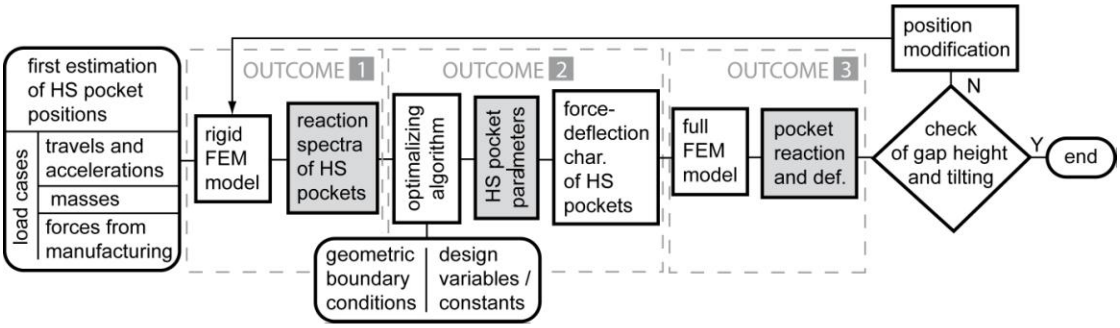

Fig. 1: Diagram showing the iterative process.

The first part of the paper is dedicated to a general description of the design optimization approach. It provides an overview of the outputs and applications of the partial results of the iteration process which include: force spectra based on a rigid FEM model; HS pocket parameters found through minimization and a well-selected object function; and force reactions and deformations computed on the basis of an FEM model of the entire machine, which are decisive for feasibility of the whole design.

In the second part of the paper, the approach is presented on an example of a real machine tool linear axis with a closed HS system controlled by constant hydraulic resistors—capillary tubes. *Genetic algorithms* (GA) have been used as a tool for optimizing dimensions for the HS pockets and the controllers. The HS pockets have been optimized with respect to the required force-deflection characteristics. The limits for the minimum pocket gap and the maximum allowable tilting of the HS pockets have been selected as the convergence criteria.

Satisfactory results were obtained-i.e. the convergence criteria were met already in the second step of the iteration process (Fig. 1). New pocket positions were found, their dimensions and capillary tube parameters were optimized. The total number of pockets remained unchanged.

The advantage of this design process combining multiparametric optimization and FEM lies in its robustness (the possibility to check for any parameter of the pocket or the guideway) and variability. The drawbacks are its demands on detailed FEM modeling. Any pocket shape and controller type can be taken into account, if their clear description exists in the fluid mechanics domain. Great variability of the optimization process is another indisputable advantage. The optimization can be based on any parameter or a combination of parameters. Instead of simple GA, the approach to designing HS guideways could be further developed by using NSGA II optimization (Deb et al., 2002), which does not use weight coefficients, and thus optimize the dimensions of the pockets and the controllers used from the point of view of more performance characteristics.

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